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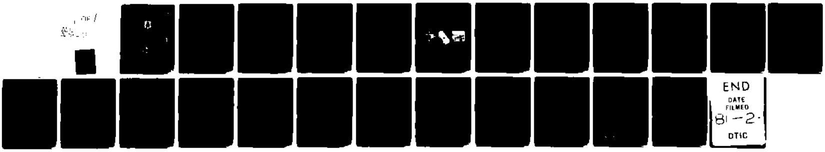

FTD-ID(RS)T-1143-80

FOREIGN TECHNOLOGY DIVISION

PROBLEMS OF RELIABILITY OF SEMICONDUCTOR INTEGRATED CIRCUITS IN PLASTIC HOUSINGS

by

Jakub Grycan

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EDITED TRANSLATION

(14) FTD-ID(RS)T-1143-80 (11) 24 Oct [redacted] 80

MICROFICHE NR: FTD-80-C-001079

(6) PROBLEMS OF RELIABILITY OF SEMICONDUCTOR INTEGRATED CIRCUITS IN PLASTIC HOUSINGS. (12) 24

By (10) Jakub/Grycan

~~English pages: 21~~

(21) Edited trans. of ~~Source~~ Elektronika [redacted] r. 9, 1973, pp. 390-396 n 9 p 390-396 1973.

Country of origin: (Poland)

Translated by: ~~LINGUISTIC SYSTEMS, INC.~~ by F33657-78-D-0618 Jozef Figa.

Requester: FTD/TQTR

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The housings of semiconductor integrated circuits, just as the housings of all electronic elements, have an essential influence on basic properties of those circuits and elements, and above all on their reliability.

The tasks of housings of semiconductor integrated circuits could be reduced to following functions:

1. Protection of semiconductor blocks of integrated circuits from harmful influences of external factors. Fulfillment of those tasks is controlled through commonly applied studies of hermeticity of the closure, of thermal shocks and of cyclical changes of the temperature, of mechanical shocks and centrifugal acceleration and by studies of the impact of moisture.

2. The adjustment of semiconductor blocks of integrated circuits to the environment. Here the essential role is played by properties of material from which housing is made, and, above all, by its capacity for heat transportation and electric parameters.

3. In the area of configuration the casing should fulfill demands which apply to geometric dimensions, height, shape, the number of leads and their distribution.

4. As far as the demarcation between the semiconductor block and the external world is concerned, the casing ensures fastening of the block, assures electric connections of the system with the outside environment and the insulation between particular leads from the system and the remaining environment.

5. In the area of costs, packaging usually constitutes a larger part of costs of the entire integrated system. While considering this problem, one has to pay attention to costs of housing itself as well as to automatization of production processes.

For production of semiconductor integrated circuits, materials such as metals, glass, ceramics and plastics are used. On Fig. 1

classification of housings of semiconductor integrated cirucits according to the construction material and closure methods is shown [2, 3].

The box-type housings of semiconductor integrated circuits are basically modified versions of transistor housings. The characteristic feature of that type of a housing is utilization of well-mastered technological processes introduced directly from the transistor production. Those housings have been thoroughly studied and display excellent hermeticity; because of that they are also called <u>hermetic</u>.

Printed casings are produced through the technique of casting or overpressed compressing and are also called <u>plastic</u>. Those housings are permeable in respect to some external factors, hence they are sometimes called <u>non-hermetic</u>. Figure 2 shows the structure of the semiconductor integrated circuit without a housing, and a semiconductor integrated circuit in a housing.

The printed (plastic) housings, apart from incomplete hermeticity, with respect to some factors demonstrate many valuable advantages; namely,

a) plastics are very well suited to cooperation with the semiconductor plate because of appropriate electric properties throughout a large range of temperature and moisture;

b) plastic housings can easily be formed into various shapes; they are also lighter, more resistant to shaking and vibrations, and they distribute heat well;

c) the prices of plastic (printed) housings are significantly lower than prices of box-type housings.

Figure 3 contains graphs illustrating formation of an average cost of housing of semiconductor integrated circuits in the years

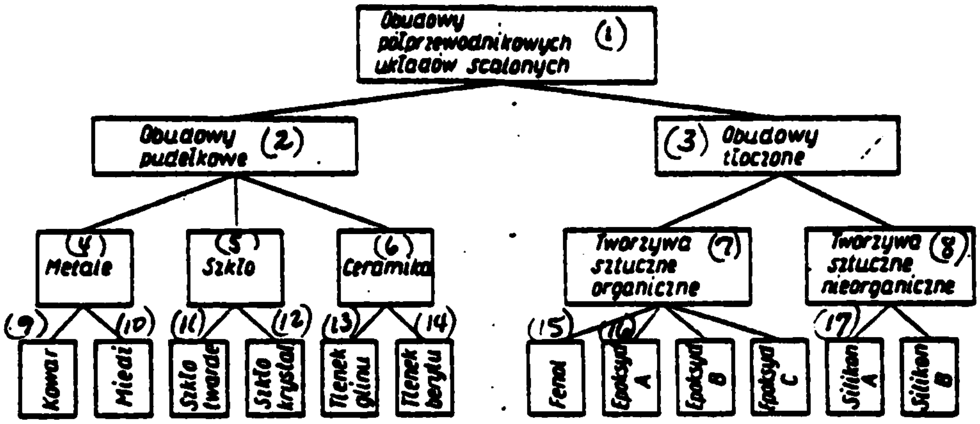


Fig. 1. Classification of casings of semiconductor integrated circuits according to construction materials and closure methods. Key: (1) Casings of semiconductor integrated circuits; (2) Box-type casings; (3) Printed casings; (4) Metals; (5) Glass; (6) Ceramics; (7) Organic plastics; (8) Inorganic plastics; (9) Iron; (10) Copper; (11) Hard glass; (12) Crystal glass; (13) Aluminum monoxide; (14) Beryllium monoxide; (15) Phenol; (16) Epoxy; (17) Silicone.

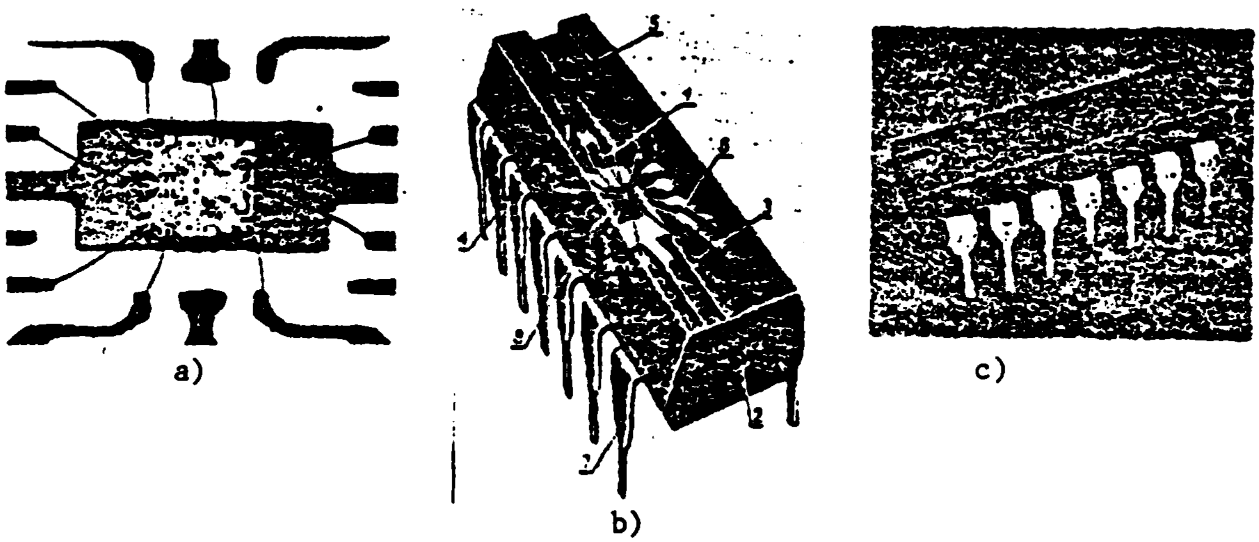


Fig. 2. Fragments of a structure of a semiconductor integrated circuit in a plastic casing. a) semiconductor block with a mosaic of an integrated circuit, a fastening prop and with the distribution of internal connections; b) semiconductor integrated circuit in a plastic casing: 1 - prop fastening the semiconductor plate, 2 - extension of the mounting prop (for heat dissipation), 3 - fastening of the leads in the casing, 4 - the connection of the lead with the bulk of the casing, 5 - the casing bulk, 6 - an internal connection, 7 - an external lead, 8 - the back of the lead facilitating automatic assembly; c) a complete semiconductor integrated circuit in a plastic casing, the dual inline type*.

*The dual inline plastic casing is also known as a Mini-dip casing.

1968-70 [4]; the characteristic feature of those dependences is a further tendency toward decrease of costs of plastic housings with costs of box-type housings remaining on the same level.

CONDITIONS AND METHODS OF INVESTIGATIONS OF RELIABILITY OF SEMICONDUCTOR INTEGRATED CIRCUITS WITH RESPECT TO THEIR CASINGS

For the purpose of an evaluation of the usefulness and the scope of the use of semiconductor integrated circuits in various casings, appropriate studies of reliability have been made. American companies and the majority of the Western European companies are making those studies on the basis of a set of military norms, like MIL. STD-883, MIL. STD-750 and MIL. STD-202C. Those studies are characterized by quite severe research conditions, in particular by severe thermic and humidity conditions. For instance:

1) The studies under operating conditions have been carried out at the temperature of +125°C ± 3°C.

2)The studies in storage conditions have been carried out at the temperature of 150°C ± 3°C.

3) The studies of a short-term thermic overload have been in two variants:

a) Temperature cycles from -65°C, (+125°C to -65°C), +200°C, 10 cycles, 30 min at each of the extreme temperatures, with the time of the transition from one state to another equal to 2 min;

b) thermal shocks from 0°C (+100°C to -65°C) +200°C, 15 cycles, 5 min at each of the extreme temperatures with the time of a transition from one state to another equal to 10 s.

4) Moisture studies:

a) Studies of the impact of steam with the relative humidity of 90-98% and cyclic changes of temperature;

b) on the impact of salt atmosphere at +35°C through 24 h.

For the purpose of illustrating the studies of reliability of semiconductor integrated circuits, in Table 1 we show examples of selectively chosen results of the studies of semiconductor integrated circuits in box-type casings which came out of the studies conducted according to the norm MIL. STD-883. Damages were classified as partial (denoted as deg) when the parameter of the integrated circuits deteriorated by more than 20%; and as total (denoted as kat.) when all capacities to function were lost [5].

Table 1

Type of a casing of an integrated circuit	Type of studies	No. of copies of integrated circuit	Number of damages		Actual time of studies, element-hours
			deg.	kat.	
Integrated circuits TTL in a metal casing	Conditions of use at +125°C	200	0	0	220,000
	Conditions of storage at 150°C	527	0	1	503,500
	Together	727	0	1	723,500
Integrated circuits TTL in a ceramic casing	Conditions of use at +125°C	184	0	0	328,000
	Conditions of storage at 150°C	460	0	1	1,122,000
	Together	644	0	1	1,450,000

On the basis of the data from Table 1, the equivalent time of functioning of a given integrated circuit at a temperature of +55°C and +25°C and, appropriately, intensity of damages per 1000 h have been summarily calculated. They are shown in Table 2.

For the calculations of the equivalent time of work at temperatures different from those which have been studied,conversion factors

have been used which have been obtained through experimental means [5, 11]. They are shown in Table 3.

Table 2

Type of casing of an integrated circuit	Actual time of studies, element-hours at an extreme temp.	Total No. of damages	Equivalent hours		Intensity of damages in % per 1000 h with 60% confidence level	
			+25°C	+55°C	+25°C	+55°C
TTL in a metal casing	723,500	1	14,929,729	5,524,000	.014	.018
TTL in a ceramic casing	1,450,000	1	30,287,567	11,206,400	.007	.018

Table 3

200°	x hour x 18.7 = equivalent hours at 55°C
150°	x hour x 8.0 = equivalent hours at 55°C
125°	x hour x 6.8 = equivalent hours at 55°C
85°	x hour x 2.5 = equivalent hours at 55°C
25°	x hour x .37 = equivalent hours at 55°C

As far as semiconductor integrated circuits in plastic casings are concerned, for some time they could not show positive results from the studies of reliability in regard to several tests based on military norms and thus they were treated with some reservations. On the "civilian" market semiconductor integrated circuits in plastic casings were treated very favorably mainly due to economic qualities.

In order to explain the problem of applicability of plastics as a material for casings of semiconductor integrated circuits several studies and analyses of plastic materials were conducted with that in mind [4, 5, 6, 7, 8].

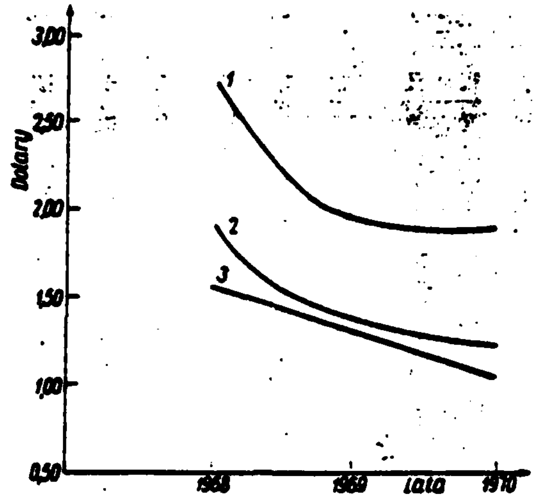


Fig. 3. Formation of average cost of casings of semiconductor integrated circuits [4]: 1 - box-type and other (flat and round); 2 - box-type dual in-line; 3 - plastic dual in-line. Key: 1 - Dollars.

ANALYSIS AND RESULTS OF STUDIES OF PLASTIC MATERIALS USED FOR PRODUCTION OF CASINGS OF SEMICONDUCTOR INTEGRATED CIRCUITS

Among many plastic materials used currently for production of casings of semiconductor integrated circuits the most suitable are plastic materials from the duroplast group, such as phenol and epoxide and also those from the group of multimolecular compounds of silicon, i.e., silicone. In the paper [4] the studies to evaluate abilities of those materials to absorb moisture and to evaluate stability of electric parameters were conducted.

For the studies two samples of silicones with a mineral filler, two samples with a glass-mineral filler, three samples of conventional epoxy A with a mineral filler,and one phenol sample with a glass-mineral filler were used.

Figure 4 shows in percentages changes in weight of those samples during their stay in the moisture chamber. According to the graph, after 10,000 h silicone samples with a mineral filler had less than .4% of the weight increase, silicones with the glass-mineral filler - less than 1.5%; the best of plastic compounds - the phenol one-had

2.6% weight increase, (i.e., almost twice as much as the silicone with the glass-mineral filler); and epoxy A samples reached from 3.1% to 4.1% weight increase.

Figure 5 displays graphs illustrating changes of the volume of the studied samples as percentage changes in the average diameter of samples as a function of the time of the impact of moisture. As those relations demonstrate, the difference among changes of geometric dimensions between organic and silicone compounds is more striking than weight changes. After 10,000 h geometric changes of silicones with the mineral filler reached .04%, while samples with the glass-mineral filler reached .14% and .16%. Among organic materials smallest changes were displayed by the phenol sample - .34%, which is more than twice the value of the highest of changes of silicone samples. The range of changes of epoxy A samples was much higher, namely from 1.1% to 1.42%.

The stability of electric parameters of samples of plastic materials can be sufficiently characterized by changes of their resistivity, electric permeability, and loss coefficient under the conditions of moisture influence. For the purpose of illustration in Tables 4, 5, and 6, consecutively, some selected results of measurements of specified electric quantities have been demonstrated. They apply to three samples of plastic materials subjected to the influence of humidity.

According to the measurement data, (Table 4), resistivity values for silicone samples are larger by at least one order of magnitude than those of the samples of organic materials, and they are subject to far smaller changes under the influence of moisture.

The changes of electric permeability (Table 5) under the influence of moisture display significant differences among silicone and organic materials. The values of electric permeability for silicones are already from the beginning very small; and after 10,000 h in the moisture chamber increased only slightly. On the other hand, permeability of organic materials increased very strongly; some of

them even surpassed accepted limits of measurability of the measuring instruments which were used, (denoted with *) and even were damaged, (denoted with **).

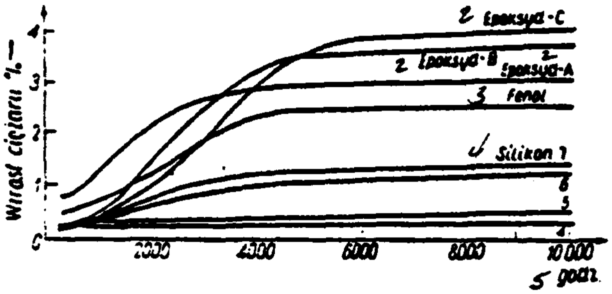


Fig. 4. Percentage changes of weight of samples as a function of the time of influence of moisture and temperature [4]: constants: 93% (relative humidity), temperature 70°C. Key: 1 - Weight increase; 2 - Epoxy; 3 - Phenol; 4 - Silicone; 5 - Hours.

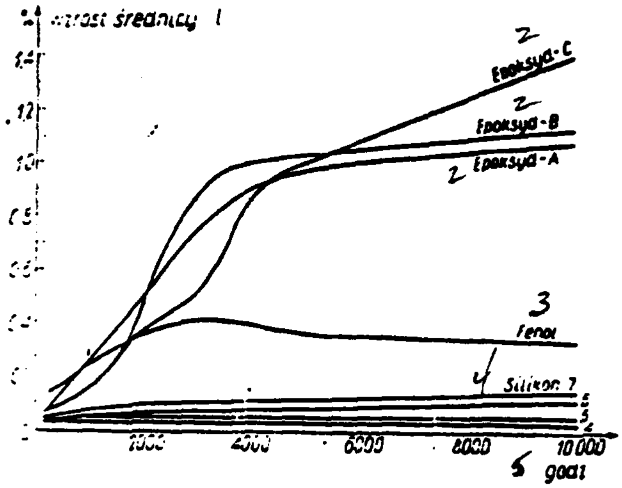


Fig. 5. Percentage changes of geometric dimensions as the function of the time of the influence of moisture and temperature; constants: 93% relative humidity, temperature 70°C. Key: 1 - Increase of the diameter; 2 - Epoxy; 3 - Phenol; 4 - Silicone; 5 - Hours.

The loss coefficient (Table 6) for the silicone samples after 10,000 h in the humidity chamber increased very slightly. The increase was also slight for the phenol samples, but from the beginning those coefficients were quite large. As far as the epoxy A materials are concerned, the values of coefficients either increased so much that they could not be measured, because of surpassing the measurement limits of the measuring bridge, (denoted with *), or were damaged (denoted with **).

It has been thought that one of the basic causes of significant changes of electric parameters of plastic materials under the influence of moisture is the contamination of those materials by ions.

Table 4

Material	Resistivity value, Ω cm		
	Initial measurement	Measurement after 5000 hours	Measurement after 10,000 hours
Silicone	5.6×10^{14}	9.1×10^{14}	7.6×10^{13}
Epoxy A	2.9×10^{13}	5.1×10^{10}	*
Phenol	8.7×10^{10}	2.3×10^{10}	1.1×10^{10}

Table 5

Material	Frequency Hz	Electric permeability		
		Initial measurement	Measurement after 5000 hours	Measurement after 10,000 hours
	10^2	3.34	3.41	3.47
Silicone	10^6	3.28	3.32	3.37
	10^2	3.95	36.90	**
Epoxy A	10^6	3.76	*	**
	10^2	10.49	38.30	34.35
Phenol	10^6	5.14	*	*

Table 6

Material	Frequency	Loss coefficient		
		Initial measurement	Measurement after 5000 hours	Measurement after 10 000 hours
	10^2	.0027	.0038	.0040
Silicone	10^6	.0018	.0017	.0031
	10^2	.0011	.39	**
Epoxy A	10^6	.0010	*	**
	10^2	.54	. 068	.57
Phenol	10^6	.046	*	*

Table 7

Material	Resistivity (Ω cm) of water extract	
	Before formation of a packaging i.e. in condition of levigation	After formation of a packaging 2 hours after hardening
Silicone	245, 000	245, 000
Epoxy A	4, 180	43, 000
Phenol	4, 580	8, 370

Table 7 shows changes of resistivity of a water extract for three samples of the studied material, i.e., for silicone, epoxy A, and phenol. Those studies measured the resistivity of water containing samples of materials before formation of the casing (i.e., in the state of levigation) and after formation. The samples were placed in de-ionized water and held there for 280 h at the temperature of 71°C. The resistivity of the water extract was measured at room temperature. According to the data from Table 6, water extracts from the samples of silicone materials have the most constant and largest resistivities, which is evidence of the lowest ion content and the best stability of electric parameters.

The above results show a decisive advantage of silicone materials over those made of plastic as far as their applicability for housings of semiconductor integrated circuits is concerned.

According to the most recent data [16] a new plastic material has been worked out which has still better properties than silicone as far as the applicability for housings of semiconductor integrated circuits is concerned. This new plastic is an amine-cured compound of diglicidyl ether of bisphenol A (dian), plus a phenolic novolac, which, to distinguish it from the conventional Epoxy A, has been named Epoxy B. As the results of the studies [16] demonstrate, properties of housings made out of that material are so good that they may as well be called totally hermetic.

ANALYSIS AND RESULTS OF STUDIES OF RELIABILITY OF SEMICONDUCTOR INTEGRATED CIRCUITS IN PLASTIC CASINGS

According to the analysis of the results of studies of plastic materials which could be used for production of housings of semiconductor integrated circuits and which was shown in the previous section, the best properties with respect to the resistance against the influence of moisture are those of silicone materials and of new epoxy (B) materials, [8, 9, 10, 11, 16].

Table 8 demonstrates results of studies of 2500 semiconductor integrated circuits in four types of plastic housings: phenol, classic epoxy A and silicone A and B. The data from Table 8 show that the lowest percentage of damages belongs to integrated circuits in silicone housings. After eliminating the integrated circuits in phenol housings from our further considerations as the least resistant to the influence of moisture, in Table 9 we show examples of the results of studies of a sample of 100 specimens of integrated circuits in epoxy A and silicone housings. The studies were conducted for 6 constraining conditions, while for the studies of resistance against moisture military norm MIL. STD-202 was used.

Table 8

The type of studies	% of damaged integrated circuits			
	In phenol packaging	In epoxy A packaging	In silicone A packaging	In silicone B packaging
Studies of durability: relative moisture 150°C*, reversed polarization, 1500 hours	7.8	4.0	2.0	0
Water steam pressure: weight increase in %	1.02	.88	.08	.13
Thermal shock	4.6	62.5	4.0	0
Water steam pressure	4.2	96.0	4.0	0
Moisture resistance; 85°C, 85% relative moisture, 168 hours	1.0	0	0	0

*[The translation is literal. There may be a printing error here.]

The results of the studies of the reliability of semiconductor integrated circuits in various plastic housings became so convincing that some companies (for instance National Semiconductor Corp.) throughout the last three years produced all of their semiconductor integrated systems in silicone housings. In Tables 10 and 11 selected examples of results of studies of semiconductor integrated circuits conducted by NSC [10, 13] are being shown. According to the data presented in Tables 10 and 11, the constraining conditions under which the studies were conducted were quite severe, and yet, in spite of that, the studied circuits in silicone housings displayed a high level of reliability.

Table 9

Type of studies	Number and type of damages of integrated circuits	
	In epoxy A packagings	In silicone packagings
Cyclic changes of temperature from -65°C to +150°C, 50° cycles.	19-total damages due to breaks	10 - total damages due to breaks
Thermal shock from 0°C to +100°C	11 - total damages due to breaks	6-total damages due to breaks
Water steam pressure (size of a sample 50 specimens of each kind)	8 - total damages due to a significant leakage	2 - total damages due to a significant leakage
Resistance to moisture; The norm MIL. STD-202, method 106	50 - total damages due to breaks, 22 - total damages due to leakage	0 - total damages due to breaks, 10 - total damages due to leakage
Study of durability after 240 hours of storage at 200°C (sample size - 50 specimens of each type)	10 -total damages due to breaks, 19 - partial damages	10 - total breaks due to breaks, 11 - partial damages
The study at +125°C with reversed polarization	3 - total damages due to breaks, 9 - partial damages	3 - total damages due to breaks, 4 - partial damages

Table 10

Type of studies	No. of specimens of housing	Actual hours of studies	No. of damages	Sum of component-hours of tests
Storage conditions at +150°C	50	1000	0	50,000
Storage conditions at -55°C	50	1000	0	50,000
Conditions at +125°C	26	250	0	6,500
Conditions at +25°C	10	1000	0	10,000
Total	136		0	

Moreover, beside those studies, integrated circuits were subjected to the impact of atmosphere with 95% humidity and, after 4000 h were exceeded, none of the integrated circuits was damaged.

We also have to pay attention to comparative studies of semiconductor integrated circuits in box-type housings and their duplicates in plastic housings which were conducted by the company Texas Instruments. Those studies are also interesting because they were conducted on the basis of the military norm MIL. STD-883. For the studies low-power semiconductor integrated circuits TTL in forms of gates, bistable elements, and 8-bit registers were used - a total of 3801 specimens which were made in 1970 and in the first half of 1971. For the studies, which lasted 18 months, 21 various tests of quality and reliability were used.

In Table 12 we show selected results of those studies which were conducted at increased temperatures, in the operating conditions and in the storage conditions for semiconductor integrated circuits in box-type housings (so-called hermetic) and in plastic housings (so-called nonhermetic).

The analysis of all of the studies under 21 constraining conditions (which, due to the small size of this paper, have not been quoted here) demonstrates that, as far as reliability is concerned, there is no difference between semiconductor integrated circuits in box-type housings and those in plastic housings.

The failure rate which was calculated for those integrated circuits was .016%/1000 h at +55°C.

According to the most recent data [16], among semiconductor integrated circuits in plastic housings the best parameters of reliability are attained by the semiconductor in housings made out of the new plastic material called epoxy B. To confirm it we may quote the data from the studies of the reliability of integrated circuits under the impact of the cyclic changes of temperature (from

Table 11

Type of studies	No. of specimens of integrated circuits	Level of overload	No. of damages	Remarks
Pressure of water steam	11	13 h	0	constant parameters
Pressure of water steam	100	13 h	1	1 wire broken
Thermal shocks 0°C-100°C	9	130 cycles	1	1 wire broken at 70 cycles
Thermal shocks 0°C-100°C	100	10 cycles	0	-
Cyclical temperature changes: -55°C/+150°C	8	130 cycles	0	-
Cyclical temperature changes: -55°C/+150°C	100	20 cycles	3	1 - short circuit 2 - a partial damage of a parameter
Resistance to moisture. Norm MIL. STD method 106	50	10 cycles	0	-
Resistance to moisture. Norm MIL. STD method 106	50	10 cycles	0	-
Salt atmosphere method 1041.1	50	24 h	0	-
Total	478		5	

-55°C to +150°C - 15 cycles). The studies of that type demonstrated that a sample of 1453 specimens of integrated circuits in silicone housings had .05% damages in the form of breaks, whereas a sample of 60,000 specimens of integrated circuits in epoxy B housings had only .01% damages in the form of breaks. Also significant are the conclusions from the studies of reliability of integrated circuits which contain elements of MOS type; as it is known, they are very sensitive

Table 12

Type of housing of integrated circuits	Type of study	No. of studied circuits	No. of damaged circuits	Time of studies, component-hours	Equivalent time of studies, component-hours at 55°C
Metal boxes	Operating conditions at +125°C	1,009	6	1,914,000	13,015,200
	Storage conditions at +150°C	1,002	2	1,152,000	9,216,000
	Storage conditions at -200°C	236	0	1,228,000	22,963,600
	Total	2,247	8		45,194,800
Ceramic boxes	Operating conditions at +125°C	150	0	150,000	1,020,000
	Storage conditions at -150°C	150	0	150,000	1,020,000
	Total	300	0		2,040,000
	Operating conditions at +125°C	40	1	160,000	1,088,000
	Storage conditions at -150°C	260	0	990,000	7,920,000
	Total	300	1		9,008,000

to the impact of moisture and other contaminations which can reach the semiconductor block. On th e basis of very rigorous studies of the impact of the environment, under norms which in some instances were more severe than military norms, it was concluded that the integrated circuits with the MOS elements in epoxy housings should have 10 to 15 times longer durability than those in other known pressed housings.

Although broad studies of integrated circuits in epoxy B housings have not yet been conducted, on the basis of previous studies it is

believed that those circuits will be able to fulfill high reliability demands which are placed in front of current integrated circuits.

DEPENDENCES ON TEMPERATURE AND MOISTURE OF DEFECT RATE OF SEMICONDUCTOR INTEGRATED CIRCUITS IN PLASTIC HOUSINGS

The defect rate of semiconductor integrated circuits in box-type housings (so-called hermetic), just as the defect rate of transistors in this type of housing, depends mainly upon temperature and is expressed by the well-known formula of Arrhenius, namely,

$$\lambda = \exp(A + BT) \qquad (1)$$

where: λ - defect rate, T - temperature, ^{o}C, A and B - constant values.

A typical graphic form of the relationship (1) is shown in Fig. 6.

Numerous studies of semiconductor integrated circuits in plastic housings, as well as studies of transistors in that type of housing, proved that the Arrhenius formula (1) cannot be used for the semiconductor elements in plastic housings in the same form as for semiconductor elements in box-type housings (hermetic) [14, 15].

According to the analysis of studies of semiconductor elements in plastic housings, their defect rate is not only a function of the temperature, but rather a function of the sum of temperature and moisture which can be expressed by formula:

$$\lambda = \exp[A + B(T + H)] \qquad (2)$$

where: λ - defect rate, (T + H) - the sum of temperature T in (^{o}C) and relative humidity H in %.

Figure 7 shows graphs of the defect rate of PNP transistors in plastic casings as a function of temperature and moisture (T + H); also values of constants A and B are given for variety of materials used for housings. On the abscissa there is the sum of temperature

and relative moisture, and at the same time relevant characteristic climatic conditions have been marked.

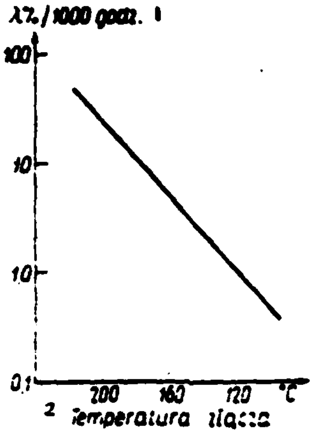
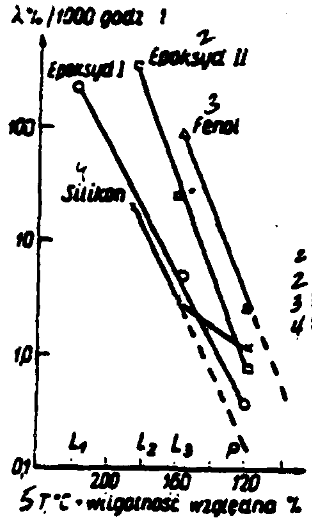


Fig. 6. A typical relationship between defect rate of elements of semiconductor (expressed in % per 1000 h) and temperature [14]. Key: 1 - h; 2 - Temperature of the joint.



6 Materiał obudowy	A	B
5 Epoksyd I	— 8,3	0,062
2 Epoksyd II	—11,67	0,086
3 Fenol	— 9,96	0,90
4 Silikon	—10,6	0,73

Fig. 7

6 Materiał obudowy	A	B
Fenol 2	—6,7	0,065
Silikon 3	—7,5	0,06

Fig. 8

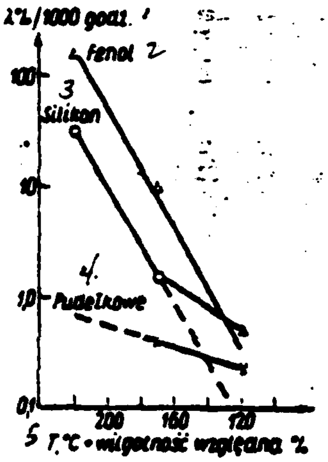


Fig. 7. Characteristics of the defect rate of PNP transistors in plastic housings (expressed in % per 1000 h) with the 90% confidence level as a function of the sum of temperature T (in °C) and relative moisture H (in %) [15]. Key: 1 - h; 2 - Epoxy; 3 - Phenol; 4 - Silicone; 5 - Temperature in °C plus relative moisture in %; 6 - Housing material.

Fig. 8. Characteristics of the defect rate of semiconductor integrated circuits in plastic housings (expressed in % per 1000 h) with 90% confidence level as a function of the sum of the temperature T (in °C) and relative moisture H (in %) [15]. Key: 1 - h; 2 - Phenol; 3 - Silicone; 4 - Box-type; 5 - relative moisture in %; 6 - Housing material.

For example, point P corresponds to the conditions of the Panama Canal Zone, point L_1 - conditions of 80^oC + 80% relative humidity, point L_2 - 94^oC + 92% relative humidity, point L_3 - the temperature conditions of the steam of boiling water. The deviation of the characteristics of transistors in silicone housings from the straight line applies to the Panama Canal Zone where, according to the measurements, monthly precipitation of salt is 3.7 mg/m^2.

Figure 8 shows dependences of defect rate on the sum of temperature and moisture for semiconductor integrated circuits in plastic housings - phenol and silicone, and, for the purpose of comparison, for those in box-type (hermetic) housings. On this graph, just as on Fig. 7, there is a deviation of the characteristics (i.e., deviation from the straight line) for semiconductor integrated circuits in silicone housings. That, too, is attributed to harmful impact of salty atmosphere. As is demonstrated by the graphs of Figs. 7 and 8, in the case of elimination of the impact of salty atmosphere, or, if the semiconductor integrated circuits were to work in conditions free from salinization of the atmosphere, semiconductor integrated circuits in plastic silicone housings could have the lowest defect rate - even lower than the integrated circuits in box-type housings, (see Fig. 8, broken line).

CONCLUSIONS

The type of housing of semiconductor integrated circuits has a very significant influence on their properties, operating characteristics, and application. The use of plastics for housings of semiconductor integrated circuits is undoubtedly a significant advance in the technology of microelectronic systems. As the cited results of studies and their analysis have shown, among semiconductor integrated circuits in housings which have been made of classic resins, i.e., epoxy A, phenolic and silicone, semiconductor integrated circuits in silicone housings display the best characteristics with respect to severe temperature - moisture conditions, and only salt atmosphere conditions decrease their reliability significantly.

Semiconductor integrated circuits in epoxy A and phenol housing are more resistant to the impact of salt atmosphere, but are more frequently damaged under the impact of moisture, temperature and during the studies for the impact of water steam.

The problem of silicone packagings and salty atmosphere is open to discussion, for one would have to think whether semiconductor integrated circuits in box-type (hermetic) housings or in plastic housings would be used directly in the environment of salt mist. Besides that, there are many applications of semiconductor integrated circuits which practically never approach oceans. Considering possibilities of the impact of salt atmosphere on an integrated circuit, we could suppose that faults in external electric connections could appear much earlier than those resulting from the penetration of salt mist inside an integrated circuit. Presently work is being done on special resins whose task is to decrease penetration of moisture and of salt mist inside an integrated circuit. Also work is being done on improving adhesion of a plastic material to metallic leads.

The progress in improving technology of semiconductor integrated circuits is taking place very fast. If as late as 1970 it was reported that semiconductor integrated circuits in plastic housings were unable to withstand some of the studies of reliability, (unlike semiconductor integrated circuits in box-type housings), already the studies from 1971-72 have shown that basically there is no difference with respect to the reliability between semiconductor integrated circuits in box-type housings and plastic housings. As the most recent data from 1973 show [16], the best reliability parameters of integrated circuits are guaranteed by housings made out of epoxy B resin.

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